International Journal of Modern Research in Engineering and Technology (IJMRET)
www.ijmret.org Volume 2 Issue 8 ǁ December 2017.

Air and Moisture Permeability of Textiles

Karel Adámek, Jan Kolář, Pavel Peukert
(Department of Numerical Simulations, VUTS Liberec, a.s., Czech Republic)

ABSTRACT : The paper contains several technical solutions of air and moisture permeability in textile layers and theirs combinations. It is useful collection of the author's knowledge from several last years. Discussed are also various marketing declarations of miraculous characteristics of individual used materials. Examples show not only own technical solution, but also the good description of ongoing processes, using the method of numerical simulation.

KEYWORDS – *air permeability flow numerical simulation, functional clothing,moisture permeability, textile materials*

I. INTRODUCTION

At the beginning, the parameters of air permeability are evaluated from comparison of measured permeability with formula used in standard commercial code. In next paragraphs, two basic cases were solved – as so-called porous jump for relative thin layers, the idealized "wire" structures of fabrics, simulated influence of wind on combined cloth layers instead complicated measuring in wind tunnel and so-called porous volume for thick layers. The results are presented as examples from real practice.

1.1 Air permeability definition

The air permeability definition presents [1] and the method was used in several solved cases [2-8] etc. The pressure resistance of observed layer against airflow velocitygives its air permeability in general. The resistance is composed from linear term, typical for instance for leaking at low velocity (so-called Darcy's law) and from quadratic term, typical for flowing in channels or around flowed bodies (Weissbach's or Moody's law). In observed real layer usually exists some combination of both such limiting cases. Used commercial software [9] describes this fact as the equation

$$\Delta p = C2 \,.\, \rho/2 \,.\, t \,.\, w^2 + \mu / \alpha \,.\, t \,.\, w,$$

where

Δp (Pa)	pressure difference
w (m/s) = V/S	flow velocity
V (m^3)	volume flow
S (m^2)	flow cross section
t (m)	layer thickness
ρ (kg/m^3)	medium density
μ (Pa.s)	dynamic viscosity
α, $C2$	two unknownpermeability parameters,depending on the layer structure.

For next treatment, it should be determine the dependence of volume flow on pressure gradient

$$V = f(\Delta p),$$

so-called flow characteristics, for sample of known cross section S transformed into

$$w = f(\Delta p).$$

Received function is inverted into the function of pressure gradient on flow velocity

$$\Delta p = f(w),$$

so-called resistance characteristics, which is formally identical with above mentioned permeability equation. The function is subsequently substituted by quadratic function

$$\Delta p = A.w^2 + B.x + C$$

and by comparison of both coefficients of linear and quadratic term with permeability equation above

$$A = C2 \,.\, \rho/2 \,.\, t$$
$$B = \mu / \alpha \,.\, t$$

the unknown permeability parameters α, $C2$ are determined as

$$C_2 = 2 \,.\, A / (\rho \,.\, t)$$
$$\alpha = \mu / (B \,.\, t).$$

They are used for definition of so-called „porous jump" in such permeable layer, which simplifies the next numerical simulation.The Fig. 1 presents typical result of such dependence of flow resistance on flow velocity $\Delta p = f(w)$.

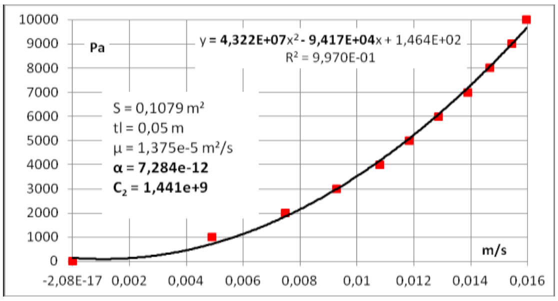

Fig.1: Permeability – flow resistance depending on flow velocity

For geometrically simple forms (as for instance perforated sheet) the dependence can be simulated, too, for complicated structures (fabric, knitwear, filtering paper etc.) must be determined experimentally. Nevertheless, for direct simulation of the flow through such complicated real layer special codes are available. Some useful information about it can be found in [10].

Note 1: The absolute term C in received quadratic function should be equal to zero, because at zero flow the flow resistance is zero, too. Non-zero value means some error in measuring or evaluation, it must be determined.

Note 2: The permeability in textile technology is defined as volume flow through an area ($m^3/s/m^2 = m/s$). The same value in fluid mechanics is so-called density of volume flow. More suitable is use of mass flow density, because the mass is objective reality, independent on state values of medium. If volume flow of a compressible medium is used, always must be defined its temperature and pressure.

Note 3: Power function $\Delta p = f\ (w^n)$, where $1<n<2$ was used in another substitution [4]. It is possible to state that such function of pressure resistance contains a combination of both first and second power of velocity as the equation above.

II. POROUS JUMP

This special boundary condition is used in [9]for simplification of created model. The inserted partition models the permeable layer, where the pressure resistance is created as sudden pressure change at the thickness of such thin permeable layer, without modelling the complicated structure of layer. Parameters of permeability are evaluated as above.

1.2 Permeability of idealized weave

Here are presented some results of flow numerical simulation in an idealized fabric structure, where idealized rigid and impermeable cylinders [1, 6] etc. substitute the individual yarns. Necessary permeability parameters are received by simulation and next calculations for similar geometries can be realized with porous jump, without creation of complicated structure.
The Fig. 2 shows the view on satin-like fabric, the Fig. 3 presents the velocity field in ground plan section across to the flow direction and just in binding points of the fabric and the Fig. 4 is the same situation, but in cross section through such idealized fabric weave along the flow direction.

It is clear that presented case is the model of flow through a wire sieve, not a fabric. Really, the individual yarns are partially permeable and deformed by forces during fabric creation, so it is necessary to determine permeability parameters experimentally and received values to enter in used numerical simulation. Such simple “wire” models can be used for mutual qualitative comparison of various weaves of fabrics or knitwear and for determination of relative permeability parameters of such idealized layers.

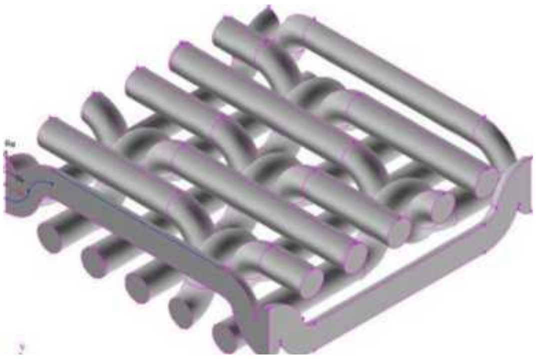

Fig. 2: Model of idealized weave (satin-like)

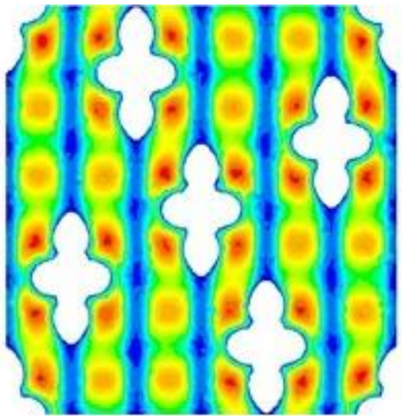

Fig. 3: Ground plan of the velocity field in idealized weave

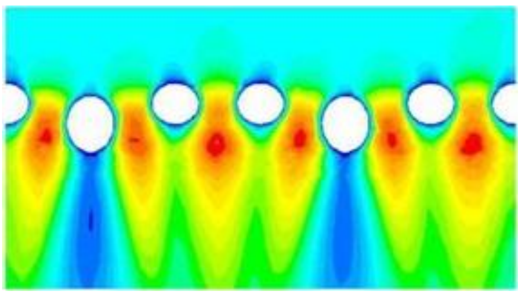

Fig. 4: Cross section of the velocity field in idealized weave

The permeability of the only one chemical yarn, composed from many elementary fibers and provided by protective twist is simulated on the model after the Fig. 5. Although its idealized geometry, the solution is very time consuming.

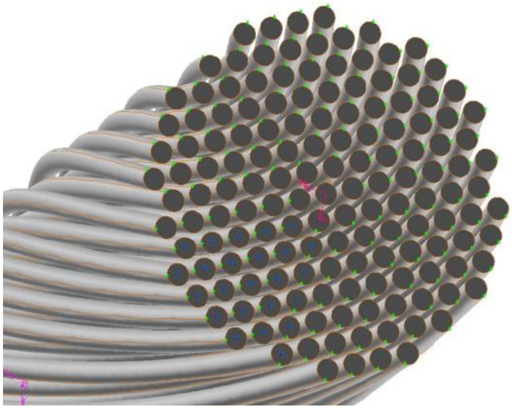

Fig. 5: Model of idealized chemical yarn composed from many elementary fibers

The complexity of real fabric is visible on the microphotography of the simple plane-weave on the Fig. 6 and on its digital evaluation on the Fig. 7 – copied from [11]. Individual yarns of created fabric are very deformed, so it is clear that the model of real weave is not possible now. The pattern of observed plain weave, which could be used as repeating elementary element of the weave, is not observable. Permeability parameters mustbe evaluated from real measuring.

Nevertheless, similar complex structures can be modelled, too, using the method developed and used in [10], where several next references can be found.

Fig. 6: Microphotography of real plane-weave

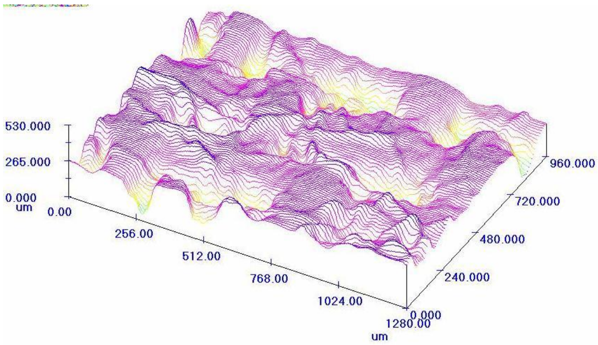

Fig. 7: Digitalized surface of real plane-weave

1.3 Textile layer permeability at higher flow velocity

In the so-called wind tunnel can be simulated the airflow through the clothing, consisting from several layers. The cylindrical wire frame, substituting the body or arm, is „dressed" in several layers of clothing. As an illustration, the result of such model is presented below.

The Fig. 8 presents streamlines around wire frame, "dressed" in individual layer, the wind direction from the left side.

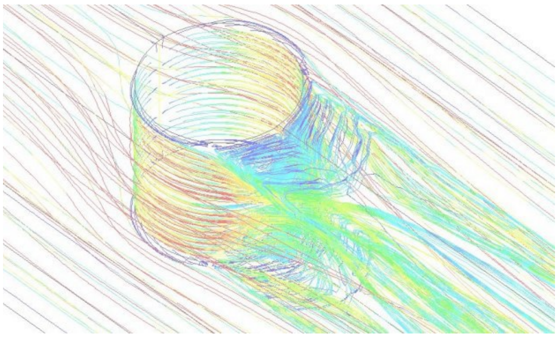

Fig. 8: Streamlines around permeable textile cylinder with wire frame

The Fig. 9 presents the ground plan of the cross section of the pressure field (symmetrical half, only). The maximum value is so-called stagnation pressure on the windward side (left); the minimum is in the area of maximum velocity (flanks).

On the Fig. 10, there is the corresponding temperature field, when the inner surface (body) is warmer than the surroundings. It is visible that on the windward side the outer cold air penetrates in the layer depth and on the contrary, on flanks the warmer air penetrates partially out into the surroundings. In the backflow area on the backside the cold air is penetrating partially into the layer of the clothing again.

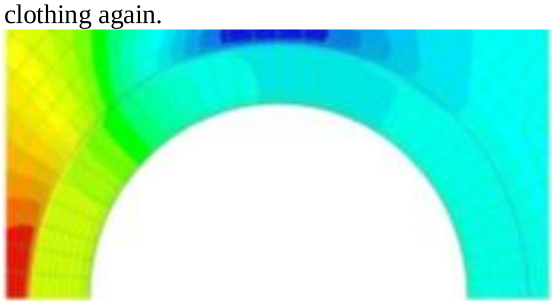

Fig. 9: Pressure field around of permeable textile cylinder (wind from the left side)

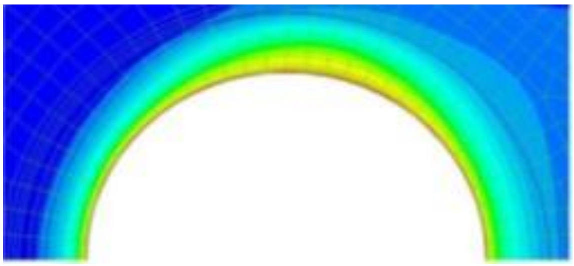

Fig. 10: Temperature field in the surroundings of permeable textile cylinder (wind from the left side)

III. RECOMMENDED CLOTHING COMBINATION

The theory of wet air together with heat transfer areused here for discussion about so-called „functional wear“, recommended for outdoor activities. Dealers of such wear (and Mr. Google, too) recommend in general the composition of three layers. The first one takes away the perspiration from the skin, the second is thermal insulation and the third is permeable for the water vapor out and impermeable for rain and wind in. What about the laws of the nature?

1.4 The first layer

The function of it is agreeable, because by the taking off the perspiration, the body skin remains dry. It is supposed that the humidity production by the perspiration is fully vaporized and is going together with air from the skin through the wear. Possible not evaporated part must be evaporated at the outer surface of this first layer, where wet surface is arising. Larger wet area means better evaporating in general, the phenomenon was discussed in [12, 13] etc.

The Fig. 11 presents the record of temperature and relative moisture of air between the body skin and the first layer (T-shirt) during the load test of 45 minutes [12] on the exercise bike in conditioned labor. Two and two sensors are placed on breast and back. Already after 15 minutes of the trial the temperature of air at backside is close to the body temperature 30.5°C and relative humidity of 95%. The corresponding dew point is here 29.5°C; it means that the state is very close to the humidity condensation. At very small temperature decreasing of this wet air a part of air humidity is condensed as liquid – after physical laws it is possible to evaporate in the given volume at given temperature certain maximum mass of water vapor, corresponding to the pressure of saturated water steam at this temperature - see [14] or any handbook of wet air.

Due to the vaporcondensation, the tested layer becomes wet, so the cooling of the body increases and temperatures are slightly decreasing, even if the test under load continues.

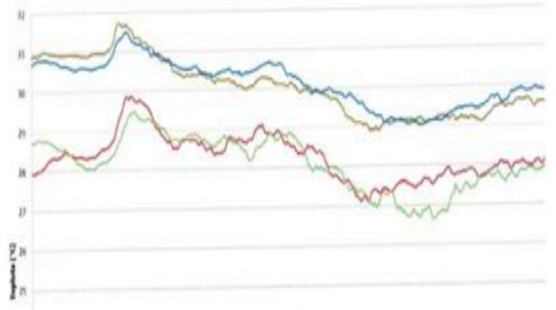

Fig. 11a: Record of temperature (range +25/+32°C) during load test of 45 min.

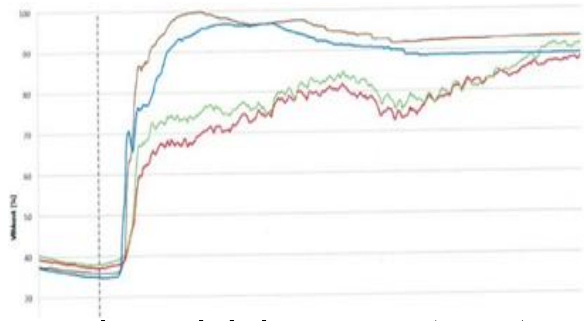

Fig. 11b: Record of relative moisture (0-100%) during load test of 45 min.

1.5 The second layer

After general physical principles the temperature at the inner side to the body (here the warmer) of the insulating layer is higher than on the outer side (here cooler). Water vapor, contained in the wet air, is going through this layer in the direction of decreasing temperature. Therefore, some part of the vapor (of air humidity) can condensate, thermal insulation becomes wet and its thermally insulating capability is decreasing. However, as mentioned below, this decreasing is not considerable. Moreover, more, the clothing must be dried after each use, to remove humidity, captured in the layer.

A little of theory: The humidity part in the wet material ω (%) is defined after handbooks for drying, for instance [10], as ratio of the humidity mv (kg) to the wet material

$$\omega = mv / (mv + ms),$$

where ms (kg) is the dry basis. It is important to note here, that this fraction (in %) ω is calculated for dry and wet material from different basis! The Fig. 12 shows the dependence of the water content as multiple of dry basis (ms=1) for different humidity fraction ω, when in dry fibers (ω = 0%, λ = 0.175 W/(m.K)) some water mass is absorbed (λ = 0.6 W/(m.K)). Really, the tested material is able to absorb some maximum water mass, depending on the structure of material and its next characteristics. The water excess, if any, is then flowing out by the gravitation.

Really, the tested material contains always some small water amount (usually several %), corresponding to the balance between the humidity in material and partial pressure of the water vapor in the surroundings. This fact is neglected here. The excessively dried material is getting wet again at this balanced state, so the energy used for such excessive drying was consumed uselessly.

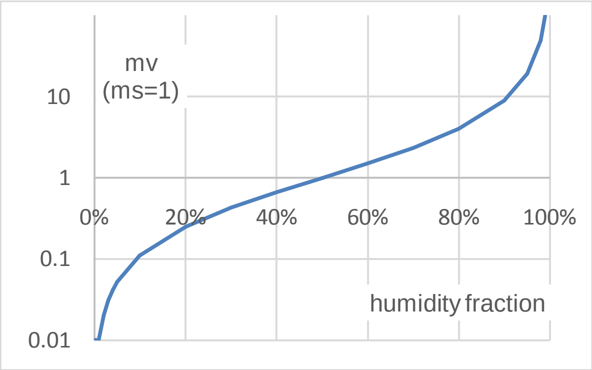

Fig. 12: Water mass depending on the humidity fraction

Supposing that the value of heat conduction coefficient λ is proportional to the material humidity, is possible to calculate it from simple balance equation for basic material of different humidity as

$$ms \,.\, \lambda s + mv \,.\, \lambda v = (ms + mv) \,.\, \lambda,$$

where s = dry basis, v = humidity, the result see the graph Fig. 13. The conductivity of former dry material in increased 2.23 times, but the absolute change for observed insulating material from 0.17 to 0.38 is not high.

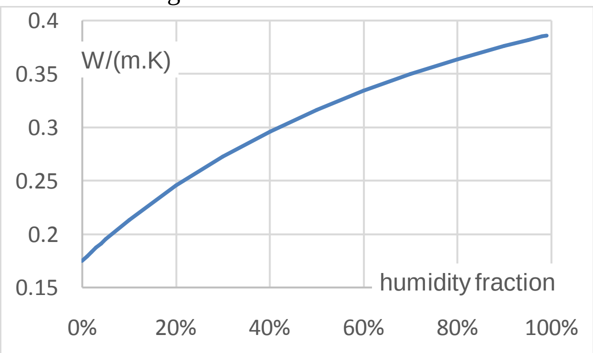

Fig. 13: Change of the heat conduction coefficient with humidity fraction

This simple consideration is theoretic, when the humidity distribution in the dry basis is fully uniform. Additionally, some mass of the condensed water is captured or spread among individual fibers by capillary forces. Therefore, the water fills the original air gaps and both thermal insulation and permeability become worse. It is clear that real mechanism of humidity transport through fiber layer is much more complicated as presented in this simple model.

The difference between temperature profiles for dry and wet insulating layer presents the next case [5]. On the inner side of this combined layer is defined solid wall (body skin) of defined temperature +27°C (300 K), on the outer side is the surrounding air (-3°C, 270 K) – the temperature difference of 30 K. On the outer side is simulated heat transfer by convection, when along the wall is flowing air (wind).

On the Fig. 14 is from left to right the temperature field in insulating layer and in surrounding air, on the Fig. 15 is the (horizontal) temperature profile in this model. Due to higher thermal conductivity (or due to lower thermal resistance) the wet insulation (dotted line) has lower temperature difference at given insulation thickness, compared with dry insulation (full line). Differences of both cases are not too high.

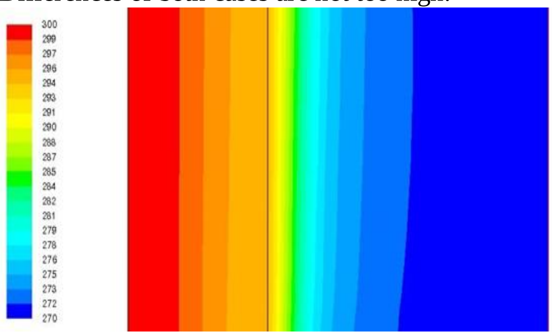

Fig. 14: Temperature field (left = insulation, right = air)

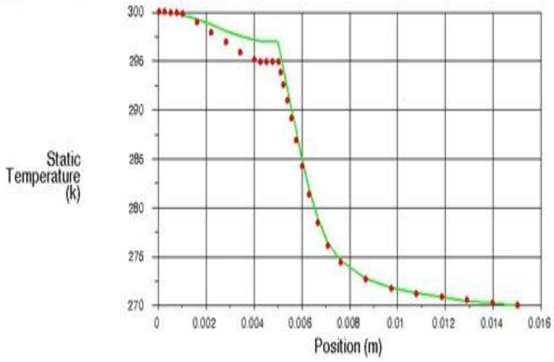

Fig. 15: Temperature profiles for wet (dotted) and dry (full) insulation

1.6 The third layer

Thermally insulating resistance of this thin layer is small, so the temperature of the inner surface is practically identical with the outer surrounding. In winter condition of the Central Europe it means, that the wet air, passed through the first and the second layer above, is on the reverse side of the third layer surely colder than its dew point temperature, thus the main part of its water content is condensed here. For information: the average temperature during heating season (from October to April approx.) for Liberec (50°N, 375 m above sea level) is +2.7°C.

After experiments in laboratory it is defined that this upper layer is impermeable for water until the pressure of 200 kPa (corresponding to the water column of 20 m!), so the water, condensed on reverse side of this third layer cannot go out. For pushing of condensate should be used the pressure over 200 kPa, but it is not real. The saturated steam temperature at this pressure is of 133°C.

Next, after laboratory experiment the very high permeability of the upper layer for water vapor is presented, until 20 kg/day/m^2 (2.3e-4 kg/s/m^2). It is practically unreal value (corresponds to 1.5 kg/h for average surface of human body of 1.8 m^2). For comparison: the experimentally determined value for very heavy physical work is 0.3-0.5 kg/h and value of 0.7 kg/s is tolerable in terms of health. Mentioned value is possible in labor, not during a standard use in cold period of the year.

This undesirable and uncomfortable effect of humidity condensation are masked by nets on reverse side, where the condensed water is absorbed (partially) or various ventilating apertures are used as some ventilation of the inner volume. By this way, the presented effect of impermeability for wind is decreased and thermal losses are increased.

Discussed case of three clothing layers was in the next solved case [5] completed by air layers among them. At a real clothing, those layers are not constant, somewhere are zero. For the same temperatures as above are solved two basic cases, only.

1. Air layers are <u>considered as rigid bodies</u> of defined thermal resistance, it means without any natural airflow inside. In short gaps, separated by zero thicknesses it could be corresponding to the reality. The result is even temperature field after the Fig. 16a, well corresponding to the simple case on the Fig. 14.

2. Air layers are <u>considered with natural air flows</u>, due to different air densities, depending on different temperatures – some heat transfer in the surroundings by convection is realized here. Images of the temperature field are influenced by defined boundary conditions, too, but their correct definition is not known.

The Fig. 16b presents the temperature field, when at the outlet up is defined lower temperature (i.e. the air closed in this gap is not influenced by the body temperature).

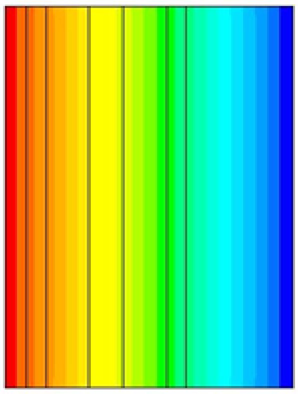

Fig. 16a: Temperature field in combined clothing layer without air flows inside

The alternative on the Fig. 16c, when on the same plane is defined higher temperature (influenced by body temperature). The deformation of the temperature field is given by boundary condition on lower and upper end of the model, which is influencing into some distance from the border. It should be necessary to create much higher model and to evaluate results in the middle of its height.

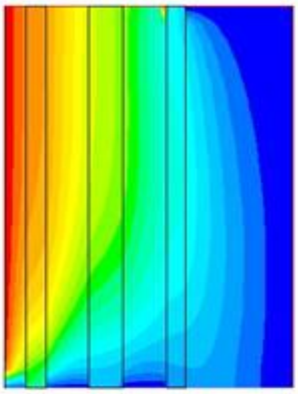

Fig. 16b: Temperature field in combined clothing layer with air flows in gaps inside, lower outlet temperature

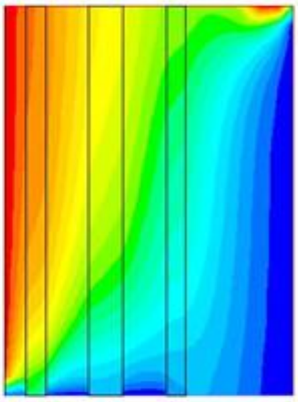

Fig. 16c: Temperature field in combined clothing layer with air flows in gaps inside, higher outlet temperature

For comparison the Fig. 17a shows temperature profiles of all three cases a-b-c – depending on boundary conditions the profiles are changing a little, but the character is the same, differences are not too high. The combination of three clothing layers and three air layers suppresses the considerable temperature gradient for two layers as on the Fig. 15.

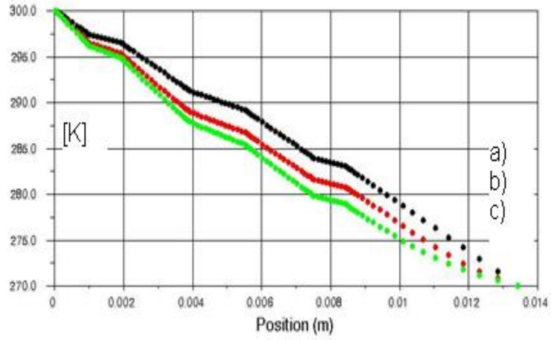

Fig. 17a: Summary of temperature profiles from previous cases

On the Fig. 17b the temperatures in individual layers are differentiated by colors. Air layers (red) of lower coefficient of heat conduction have higher gradient of temperature decreasing, comparing with textiles layers (blue, green, cyan), which have higher coefficient of heat conduction in general. The outer air (black) is defined here as rigid body, without airflow, its temperature is constant.

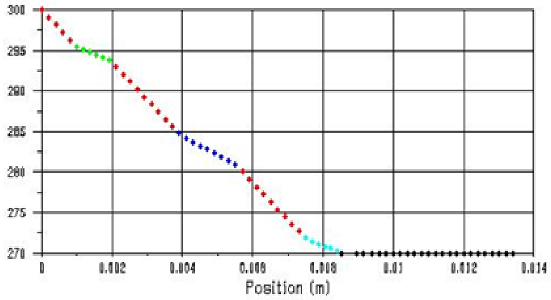

Fig. 17b: *Temperature profiles of individual layers*

1.7 Conclusion:

During the cold period in the Central Europe, the temperature on the reverse side of the thin upper layer of clothing is practically identical with the surrounding temperature. During physical activity of testing person, both temperature and relative humidity are high in the skin vicinity. At small temperature drop of this air during its passing through tested clothing combination practically in every case the temperature is decreasing under its dew point temperature and some air humidity is condensed. However, the condensed water cannot pass through outer membrane, which is impermeable for liquid water and wind, the thermally insulating layer becomes moist. Thermally insulating parameters are worse, see the Fig. 13 and more heat is going from the skin into the surroundings. Partially, it could be an advantage, because at hard work the body is better chilled.

Presented very high values of water vapor permeability, reached in laboratory, are not reached in the practice, due to the existence of natural physical laws. To have a conformity of laboratory experiment and reality it should be to have outside temperature 30°C approx., but in such case it is not necessary to wear the recommended combination of three layers - the first layer, only, is sufficient.

Similarly, the proclaimed advantage of high water impermeability becomes the disadvantage at practically unavoidable condensation of air humidity at the reverse side of the clothing.

IV. POROUS VOLUME

Next cases solve the permeability of thick layers, for instance blocks of insulating materials, car seats etc., where the thickness must be simulated as real value. Usually it can be supposed the homogenous value of permeability in different directions of this volume.

1.8 Permeability of bobbin winding

This case solves the pigment flow in the mass of wound bobbin [7, 8]. The pressurized liquid is flowing through the central cavity and then through the wound yarn layer, which is of different thickness, depending on both flow direction and bobbin shape. For solved situation the model is slightly modified – the continuous value of permeability is replaced by system of partial permeabilities among individual elementary volumes in the permeable volume of the winding. The standard code [9] enables to use spatial „porous volume", too.

The Fig. 18 presents streamlines incoming along the bobbin axis, further through the perforated wall of bobbin core and further through the permeable wound volume in the free surroundings. Modelled as axis-symmetrical case, therefore the one-half is presented here, with axis of symmetry situated down.

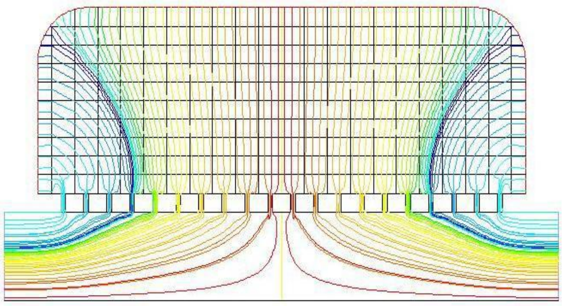

Fig. 18: Streamlines in the permeable winding

Next Fig. 19 presents the relevant pressure field and the Fig. 20 presents the velocity field (the scale is suppressed here, to get fine differentiation of the flow in permeable winding).

It is visible that considerable part is flowing out as short-circuit across the face of winding on minimum radius, although streamlines make here the bend of 180° practically. To be sure, that the dyeing will be uniform in the whole volume, it is necessary to suppress such short-circuit flow, for instance by applying of impermeable partition along the winding face. Otherwise, it should be to prolong the dyeing time, to get uniform dyeing in the whole volume, but in such case, the output is lower.

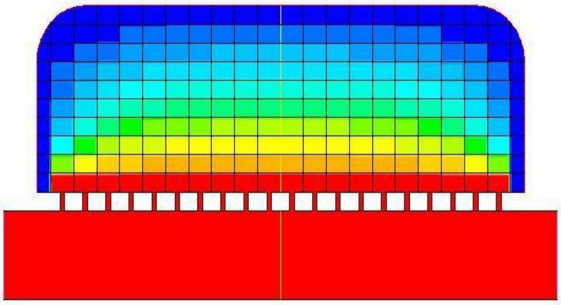

Fig. 19: Pressure field in the volume of winding – flow from the axis to the periphery

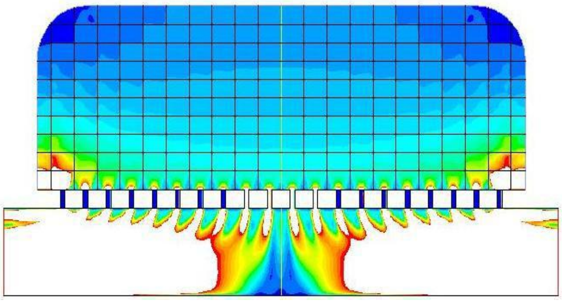

Fig. 20: Velocity field in the volume of winding – flow from the axis to the periphery (suppressed scale)

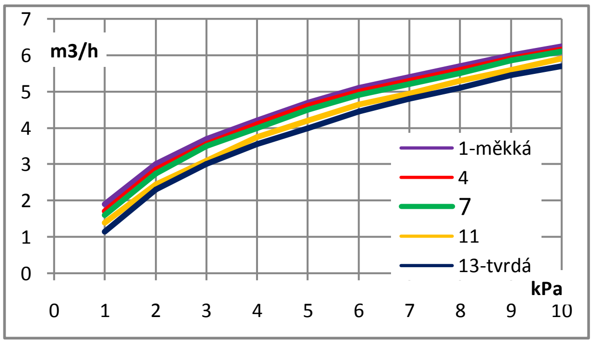

Fig. 21: Permeability of measured bobbin samples (1 = soft, 13 = hard)

Flow numerical simulation in permeable layer indicates that uneven coloring of individual bobbins can be caused by differently stiff (permeable) winding of each bobbin, too – for instance by uneven tension of wound yarn. In addition to that, the uneven coloring of volume of individual bobbin can be found, too. At very short coloring time, the uneven flow intensity through individual elements of bobbin volume can affect on uneven coloring of material.

The Fig. 21 shows different measured permeability characteristics V = f (Δp) for soft (1) – medium (7) - hard (13) bobbin, given by small-medium-high tension of wound yarn. The different volume flow through wound bobbins can be used as parameter of different stiffness [7].

1.9 Permeability of thick foam layer

Car seats are manufactured from various perforated foams, for instance on the Fig. 22 of different size and pitch of continuous holes, blind grooves etc., see [15] etc, – in the next text marked as F0 (foam only), F1-F2-F3 (as different perforated foams).

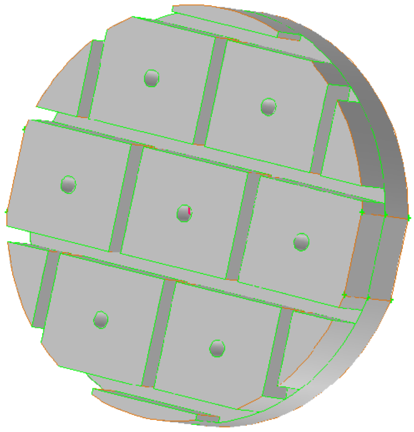

Fig. 22: Example of perforated and grooved foam

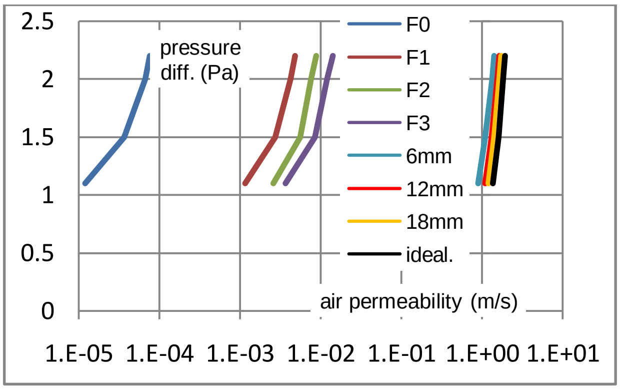

Fig. 23: Inversed and recalculated permeability characteristic in semi-logarithmic scale

On the Fig. 23, using semi-logarithmic scale, it is visible that measured permeability of the full foam F0 is of two orders lower than for perforated foams F1-F2-F3 in general and simulated „permeability“ of simple hole of various diameter is of next three orders higher.

As an illustration, next serial of Figures presents details of the flow field in several cross sections of solved volume of perforated foam. In general, the absolute majority of the air (99%) flows through continuous holes and very low volume, only, flows through the foam. Therefore, for better displaying of flow details in the foam volume the suppressed scales are used here.

It is possible to state that the foam volume serves as a soft cushion, only, and its permeability is realized mostly through holes. It is in the compliance with general theory – let us to imagine that the foam volume consists from many flow resistances in parallel, some of them of low value (holes) and some of them of high value (foam), some of them of any value between (foam + groove).

The inlet pressure on the Fig. 24 penetrates into blind grooves and stops at the grooves bottom. In continuous holes, the pressure value is very low, because is changed into kinetic energy of the flow.

The main flow on the Fig. 25 is through continuous holes, the maximum velocity value of 2.1 m/s corresponds to the theoretical value for defined pressure difference of 3 Pa. The flow through foam volume is very low, on the image of the full scale without any visible details.

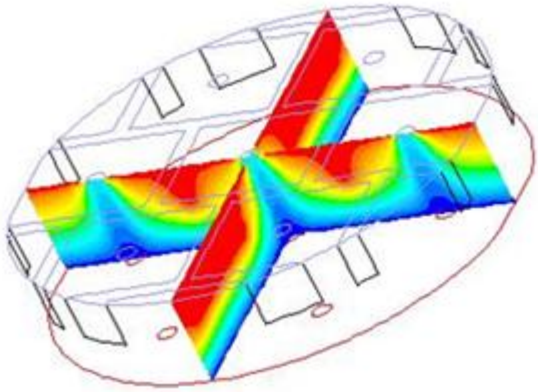

Fig. 24: Pressure field in axial cross section

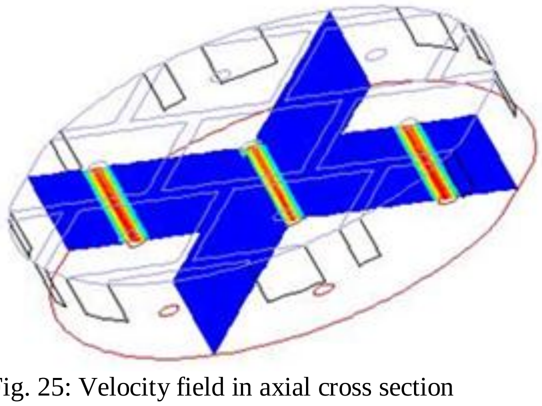

Fig. 25: Velocity field in axial cross section

To display details of the previous Fig. 25 it is necessary to use suppressed scale, order of 10^{-4} m/s, see the Fig. 26. The flow stops at the grooves bottom and slightly is penetrating in the foam volume. The simulation of such full geometry can explain flow details in permeable and perforated foam volume.

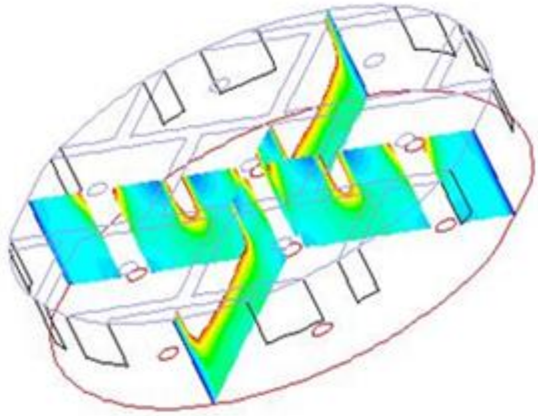

Fig. 26: Velocity field in axial cross section (suppressed scale)

The next Fig. 27 presents the velocity field on the inlet plane of the foam, with suppressed scale again. It is visible, that quick flows through continuous holes induce some flow in the narrow adjacent volume of foam just along holes surfaces.

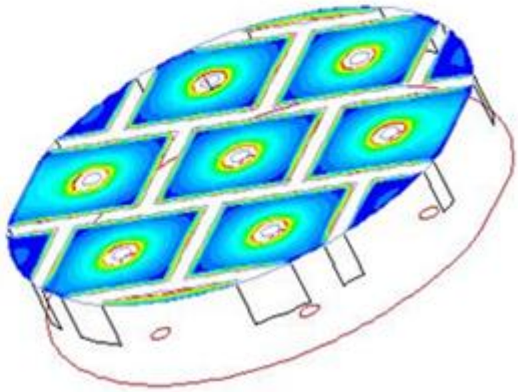

Fig. 27: Velocity field at foam inlet plane

In the Fig. 28 there is presented the velocity field at the inlet plane of grooves. The suitable scale of low velocities is used again, to display just the field in grooves. There are visible local maxima in larger cross sections (T-junctions);finer meshingcould repair individual irregularities.

Last Fig. 29 presents the velocity on surfaces of continuous holes. Those values are not zero, as on the rigid walls, because the walls are here permeable a little and in the foam volume is any low, but non-zero velocity. Real values of 0.3 – 0.7 m/s approx. are lower than maximum of axial velocity, here of 1.3 m/s. On walls of peripheral holes, there are visible higher values than in the middle of the foam volume, probably due to some influence of peripheral boundary condition, maybe in the combination with relatively coarse mesh.

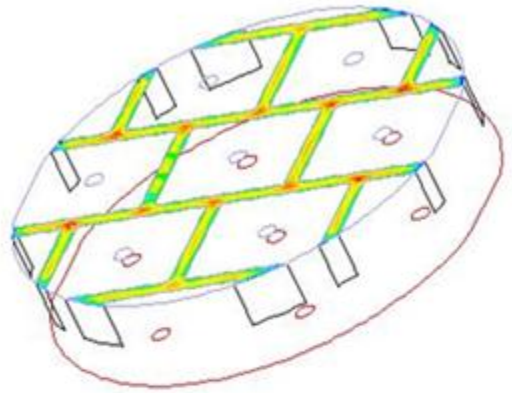

Fig. 28: Velocity field at the inlet in grooves

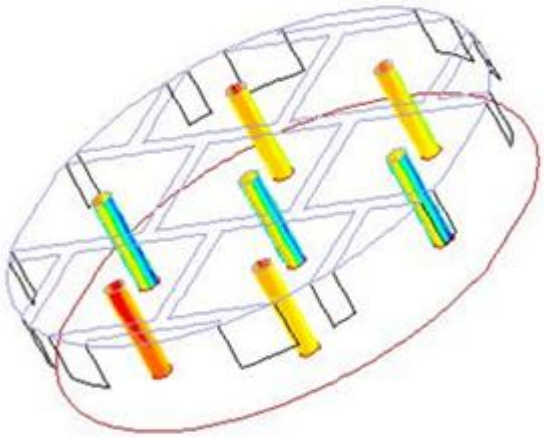

Fig. 29: Velocity field at walls of continuous holes

For comparison with previous detailed models the simple model of „foam cake“ was solved, too, for both cases of F0 and F1. Their permeability parameters were evaluated from measured values, so for the perforated foam Fl it means some average value. Therefore in such „cake“ model it is not possible to see details of the flow field in holes, grooves and foam as above, but the averaged flow, only.

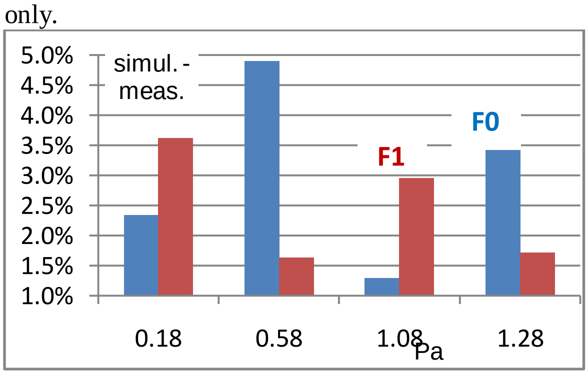

Fig. 30: Difference between measured and simulated mass flow for foams F0 and F1

The comparison of measured and simulated flows is presented on the Fig. 30. The differences are 1-5%, only, which is fully comparable with standard error of usual measuring devices (4%). The reason of it could be the imprecision of numerical simulation, coarse mesh etc. – not examined more.

In the geometry of previous model is added thin inlet textile layer, to separate the inlet plane (3 Pa) from permeability plane (pressure jump) – in one plane cannot be defined two different boundary conditions. As the upper layer were used various materials from [15], to represent low, middle and high permeability. The main results are as follows.

<u>Without added upper layer:</u>
This case is solved to test the influence of above mentioned thin volume, added between boundary conditions „inlet“ and „porous jump“. Results are similar to above mentioned basic case, where the main air flow through holes (99%) and negligible flow through the foam (1%).

The flow of such changed model is of 24% higher. This difference is given probably by another geometry and mesh of both compared cases, of changed flow character etc. – not examined more.

<u>With added upper layer</u>:
The added upper layer decreases the total flow, first in holes. The flow through holes (both the relative in % and the absolute in kg/s) is now comparable with flow through the foam and so the ratio foam + holes is changing from the ratio 46% + 54% to the ratio 30% + 70%, depending on the permeability of used upper layer.

The relative flow through the foam is a little higher (of some %), depending on the permeability of used upper layer. However, the absolute value of this flow and its change can be neglected.

For given geometries the flow through foam volume represents typically 1% approx. of the total flow, the absolute maximum is the flow through continuous holes. Therefore, any changes of foam permeability cannot influence the total permeability of such combined case with grooves and holes. The main influence on the total flow has here the flow through continuous holes; the flow through foam volume is negligible.

V. CONCLUSIONS

In individual sections, there are combined basic principles and equations of fluid mechanics and thermomechanics together with actual practical applications. Basic principles are repeated and more, real technical applications show, how such simple theoretical principles become complicated at the transition from simple one-dimensional case, presented in textbooks into 3-dimensional reality, which can be displayed using numerical simulation of appropriate flow field. The substance of assigned technical problem is often complex. So the knowledge of fluid mechanics and thermomechanics is not sufficient, often it is necessary to use knowledge of other parts of engineering – theory of kinematic, dynamic, elasticity, materials and last but not least mathematics, of course. The knowledge of used technological procedures is an advantage, too.

Presented cases are not complete listing of possible solutions and reached results, but typical procedures, only.

Our practice confirmed that flow numerical applications for cases from technical practice brings several principal advantages:

1) Relative simple verification of fully new hypothesis of the solution. Only this one, which seems to be realizable, is then manufactured and tested.

2) At actual systems is possible to find out the reason of its wrong or insufficient function and usually to propose suitable remedy.

3) It is possible to simulate the flow field in small or inaccessible areas, where it is not possible use any experimental procedures or sensors for determination of needed values.

Some of the knowledge mentioned in references are unique and actual. In any case, it is not any complex bibliographical overview, relevant to applications of fluid mechanics and thermomechanics in textile machinery, textile technologies and supporting areas, but only some actual references on actual applications.

VI. Acknowledgements

Our acknowledgment is given to VUTS Liberec – Center for Development in Machinery Research for the support in the framework of the grant NPU-LO1213, “National program of sustainability”, granted by the Ministry of education, youth and sports.

References

[1] K. Adámek, Permeability of textile layers (Prodyšnost textilních vrstev), *Proc. of the Applic. of experiment. and numer. meth in fluid mech*., 6 p., ŽU Žilina, 2008

[2] R. Šubert, *Evaluation of textiles permeability at higher flow velocities* (Hodnocení prodyšnosti textilií při vyšších rychlostech proudění), dissertation KOD FT TU Liberec, 2006

[3] A. Halasová, *Contribution to evaluation of clothing sandwiches under conditions of quickly flowing air* (Příspěvek k hodnocení oděvních sendvičů v podmínkách rychle proudícího vzduchu), dissertation KOD FT TU Liberec, 2007

[4] M. Havrdová, *Contribution to the permeability evaluation of clothing fabrics* (Příspěvek k hodnocení prodyšnosti oděvních tkanin, dissertation KOD FT TU Liberec, 2004

[5] A. Havelka, K. Adámek, L. Nagy, Z. Kůs, Transport properties of barrier textiles for sports and functional applications, *Proc.ofCLOTECH 2015*, Politechnika Łódzka, Łódž, Poland, 2015

[6] K. Adámek,Flow simulations in textile technologies (Simulace proudění v textilních technologiích), *TRANSFER* No. 20, Vol. 8, VZLÚ Praha, 2013

[7] P. Škop, P. Klouček, N. Pomp, K. Adámek, Method of bobbins classifications after their wound stiffness and device for determination of it (Způsob třídění cívek podle tuhosti návinu příze a zařízení ke zjišťování prodyšnosti návinu), Patent CZ 304933, 2014

[8] K. Adámek, Permeability of winding on the bobbin core, New developments in mechanics and mecanical engineering, *Proc. of the Int. Conf. on Mech. Eng*., Vienna, 2015

[9] Fluent v. 6.3.26

[10] www.itwm.fraunhofer.de - Annual reports of Fraunhofer ITWM Kaiserslautern, Germany, Dept. of flow and material simulation

[11] M. Viková, *Measuring of microstructure of fabric surface* (unpublished protocol, in Czech), FT TU Liberec, 2007

[12] L. Nagy, *Evaluation of physiological characteristics of the clothing first layer* (Hodnocení fyziologických vlastností první vrstvy oděvu), dissertation KOD FT TUL, 2014

[13] M. H. Motawe, *Factors affecting garment´s thermal and ophysiological properties in tropical weathers countries*, dissertation KOD FT TU Liberec, 2013

[14] J. Chyský, Wet air (Vlhký vzduch), SNTL Praha, 1963

[15] K. Adámek, J. Kolář, P. Peukert, P., F. Buyuk Mazari, and A. Mazari,Numerical Simulation of Air Permeability through carseat’s foam, *Yarn and Textiles in Eastern Europe*, Lódž, Poland (printed in 2018)